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# EVALUATION OF SUPPRESSION OF SYNTHETIC PARAFFINIC KEROSENE (SPK) FUEL FIRES WITH AQUEOUS FILM FORMING FOAM (AFFF)

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**14. ABSTRACT**

Synthetic fuels have been selected as an alternative energy source to petroleum-based fuels by the United States Air Force (USAF) and have been recently performance tested in both aircraft and ground vehicles by the USAF. Pending successful evaluation, the wide spread usage of these fuels is expected to increase throughout the military in the near future. In response to this transition, the USAF Fire Panel requested the Air Force Research Laboratory Fire Research Team (AFRL/RXQD) to evaluate the extinguishment performance of Aqueous Film-Forming Foam (AFFF) on synthetic fuel fires to aid Air Force firefighters' response to an incident. Results show that AFFF can extinguish synthetic fuel fires with the same level of success as compared to conventional fuel fires. Consequently, USAF fire protection services will not have to make significant modifications to fire fighting equipment or procedures when combating synthetic fuel spill fires.

**15. SUBJECT TERMS**

Synthetic fuels, JP-8, Synthetic JP-8, Synthetic Paraffinic Kerosene (SPK), Synthetic Diesel, Blended fuels, Shell FT-IPK, Syntroleum S-8, Syntroleum S-2

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## 1.0 Summary

### 1.1 Background

As an alternative to JP-8 fuel for aircraft, evaluations have commenced to certify synthetic fuels in all United States Air Force (USAF) aircraft, as demonstrated in recent test flights. Used in the trial flights was a 50/50 blend of conventional JP-8 and Synthetic Paraffinic Kerosene (SPK) derived from a Fischer-Tropsch (FT) process. The FT process converts gases, such as hydrogen and carbon monoxide, into liquid hydrocarbons. With the increased interest in synthetic fuels, there are questions of whether existing Aqueous Film Forming Foam (AFFF) firefighting agents and equipment are capable of extinguishing synthetic fuel fires or if firefighters will need additional or new tools to successfully extinguish these fires.

### 1.2 Scope

This program was designed to determine if Military Specification MIL-F-24385F (MIL-SPEC) AFFF has the capability of extinguishing synthetic fuel fires and SPK/JP-8 blended fuel fires. The fuel and blended fuel fires were evaluated for their ability to be suppressed by existing military fire fighting agents and techniques. The assessment included extinguishment effectiveness, extinguishment time, and burn-back time. Fuels evaluated in this program were conventional JP-8 jet fuel (specified by MIL-DTL-83133F), two synthetic jet fuels produced by Syntroleum Corporation (S-8) and Shell (FT-IPK), Synthetic Diesel (S-2), and Conventional Diesel.

### 1.3 Conclusions

Test results show AFFF and existing firefighting equipment will extinguish the tested synthetic fuel fires just as effectively as conventional fuel fires. It is recommended that each new fuel undergo a minimum series of evaluations using the methods discussed in this report to ensure the safety of firefighters and effectiveness of firefighting equipment and agents.

## 2.0 Introduction

### 2.1 Background

The United States Air Force (USAF) has an interest in minimizing dependency on foreign oil. As an alternative to JP-8 fuel for aircraft, evaluations have commenced to certify synthetic fuels in all USAF aircraft, as demonstrated in recent test flights. Used in the trial flights was a 50/50 blend of conventional JP-8 and Synthetic Paraffinic Kerosene (SPK) derived from a Fischer-Tropsch (FT) process. The FT process converts gases, such as hydrogen and carbon monoxide, into liquid hydrocarbons.

Aqueous Film Forming Foam (AFFF) is used by Air Force fire departments to extinguish fuel spill fires involving jet fuel (JP-8), diesel, or gasoline. With the increased interest in synthetic fuels, there are questions of whether existing AFFF firefighting agents and equipment are capable of extinguishing synthetic fuel fires or if firefighters will need additional or new tools to successfully extinguish these fires.

### 2.2 Scope

To aid Air Force firefighters' response to an incident involving SPK fuels, this program was designed to determine if Military Specification MIL-F-24385F (MIL-SPEC) AFFF has the capability of extinguishing SPK fuel fires and SPK/JP-8 blended fuel fires. This evaluation mostly followed parameters set forth in the MIL-SPEC guidelines, MIL-F-24385F, Section 4.7.13 for a 28 $ft^2$ fire test. The fuel and blended fuel fires were evaluated for their ability to be suppressed by existing military fire fighting agents and techniques. The assessment included extinguishment effectiveness, extinguishment time, and burn-back time as well as qualitative information about the smoke thickness for these synthetic fuels compared to JP-8.

### 2.3 Fuels Tested

Fire tests were performed on various commercially available fuels that can be divided into two categories: kerosene fuels and diesel fuels. The kerosene fuels consisted of the conventional JP-8 jet fuel (MIL-DTL-83133F) that is currently used by the Air Force and two synthetic jet fuels produced by Syntroleum Corporation (S-8) and Shell's Fischer-Tropsch iso-paraffinic kerosene (FT-IPK). The synthetic kerosene fuels are also known as SPK or synthetic paraffinic kerosene. Diesel fuels consisted of conventional diesel as well as a synthetic diesel (S-2) produced by Syntroleum Corporation. All of these fuels, except conventional diesel, were evaluated for fire suppression. Conventional JP-8 was used as a baseline to which all other fuels were compared.

The physical properties of these kerosene (Moses 2001) and diesel (Woodward 2001) fuels have been previously studied. Some physical properties pertinent to combustion have been tabulated and are presented in Table 1. Since the data in Table 1 came from various sources, not all test methods in Table 1 were performed at the same location, nor were the same methods used to determine the same physical parameter. However, this data gives a reasonable estimate of overall properties of the various fuels.

Table 1: Physical properties for fuels used in fire suppression experiments

| Property | SPK Test Method | S-8 | SHELL (FT-IPK) | JP-8 Edwards | JP-8 Dyess | JP-8/S-8 Edwards | JP-8/FT-IPK Dyess | Diesel Test Method | S-2 | EPA #2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **COMPOSITION** | | | | | | | | | | |
| Aromatics (volume %) | NA | 0 | 0.2 | 16.5 | 19.1 | 8.3 | 8.7 | ASTM D - 1319 | ND | 30 |
| Olefins (volume %) | NA | NA | NA | NA | NA | NA | NA | ASTM D - 1319 | ND | 1 |
| Saturates (volume %) | NA | NA | NA | NA | NA | NA | NA | ASTM D - 1319 | > 99 | 69 |
| Total sulfur (mass %) | ASTM D - 4294/2622* | 0.002 | < 0.01 | 0.06 | 0.09 | 0.029 | 0.05 | ASTM D - 2622 | ND | 0.05 |
| Hydrogen content (mass %) | NA | 15.4 | NA | 13.8 | 13.7 | 14.5 | 14.6 | NA | NA | NA |
| Particulate matter (mass %) | NA | 1.3E-04 | NA | NA | NA | NA | NA | ASTM D - 482 | < 0.001 | 0.01 |
| **VOLATILITY** | | | | | | | | | | |
| Initial boiling point (°C) | ASTM D - 86 | 144 | 154.1 | 145 | 182 | 148 | 160 | ASTM D - 86 | 160 | 184 |
| 10% recovered (°C) | ASTM D - 86 | 167 | 160.8 | 172 | 196 | 170 | 171 | ASTM D - 86 | 199 | 216 |
| 20% recovered (°C) | ASTM D - 86 | 177 | 162.3 | 181 | 200 | 179 | 175 | NA | NA | NA |
| 50% recovered (°C) | ASTM D - 86 | 206 | 168.0 | 205 | 209 | 206 | 188 | ASTM D - 86 | 256 | 258 |
| 90% recovered (°C) | ASTM D - 86 | 256 | 183.3 | 252 | 224 | 253 | 216 | ASTM D - 86 | 316 | 310 |
| Final boiling point (°C) | ASTM D - 86 | 275 | 195.2 | 277 | 244 | 275 | 236 | ASTM D - 86 | 350 | 341 |
| Residue (%) | ASTM D - 86 | 1.5 | 1.0 | 1.3 | 1.1 | 1.3 | 1.0 | NA | NA | NA |
| Loss (%) | ASTM D - 86 | 0.9 | 1.0 | 1.3 | 0.6 | 1.1 | 0.3 | NA | NA | NA |
| Flash point (°C) | NA | 45 | 43 | 48 | 64 | 48 | 50 | ASTM D - 93 | 64 | 69 |
| **OTHER TESTS** | | | | | | | | | | |
| Density (kg/m$^3$) | ASTM D - 4052 | 756 | 736 | 807 | 808 | 782 | 773 | ASTM D - 1298 | 770 | 845 |
| Freezing point (°C) | ASTM - 2386/5972* | -51 | -53.8 | -52 | -52 | -52 | -61 | NA | NA | NA |
| Viscosity (cSt) | ASTM D - 445† | 4.9 | 2.49 | 4.8 | 4.9 | 4.6 | 3.6 | ASTM D - 445‡ | 2.1 | 2.5 |
| Net heat of combustion (MJ/kg)¥ | ASTM D - 3338/4809/4529* | 43.9 | 44.2 | 43.2 | 43.1 | 43.4 | 43.5 | ASTM D-240 | 42.4 | NA |
| Lubricity (mm) | ASTM D - 5001 | 0.58 | 0.92 | 0.56 | 0.53 | 0.54 | 0.54 | ASTM D - 6079 | < 0.37 | NA |
| Acidity (mg KOH/g) | ASTM D - 3242 | 0.004 | 0.003 | 0.004 | 0.004 | 0.005 | 0.003 | NA | NA | NA |

NA - Not Available, ND - Not Detectable, *Test methods varied between fuels or multiple tests were performed and an average was given, †@ -20°C, ‡@ 40°C, ¥High heating value
SPK Fuels taken from Moses (2008), Diesel Fuels taken from Woodward (2001)

The flash point of a liquid is the lowest temperature at which its flammable vapors will ignite when an ignition source is applied. It is indicative of the overall flammability of the fuel. Those fuels with higher flash points are less volatile. Fuels that are below their flash point temperature typically take longer to ignite and burn than fuels that are above their flash points. The flash points found in the manufacturer's MSDS for these various fuels are shown in Table 2. These flash point values varied somewhat from those found in Table 1.

**Table 2: Commercially available fuels used in fire suppression experiments**

| FUEL | MANUFACTURER | FLASH POINT |
|---|---|---|
| Synthetic JP-8 (S-8) | Syntroleum Corporation | 100-125°F (37.8 - 51.5°C) |
| Synthetic JP-8 (FT-IPK) | Shell Oil Products | 100°F (38°C ) |
| Conventional Jet Fuel (JP-8) | Shell Oil Products/ Mobil | > 100°F (> 38°C) |
| Synthetic Diesel (S-2) | Syntroleum Corporation | 141°F (> 60.5°C) |
| Conventional Diesel | Shell Oil Products | 143°F (> 62°C) |

## 3.0 Lab-Scale Evaluations

### 3.1 Description

A series of laboratory evaluations were performed to examine the relative heat output of the flames in small-scale fires before larger scale fire suppression evaluations were conducted. The small-scale fires were performed inside an 8-foot x 10-foot walk-in laboratory hood. Incident heat flux measurements were recorded using a total heat flux gauge. The heat flux gauge was strategically placed facing the flames from burning fuel in the porcelain pan, which simulates a firefighter fighting a MIL-SPEC AFFF fire. The data from the behavior of synthetic fuels versus traditional fuels was measured to compare flame performance.

Flash point and density tests were also conducted on the synthetic fuels to verify the properties of each fuel.

### 3.2 Procedures

A 6.5-inch diameter porcelain pan (0.23 $ft^2$) was placed in the center of the hood, on a mass balance (Ohaus EP 8100), with a heat flux gauge (Medtherm 64-25-20) positioned 12-inches above the outer border of the pan and six-inches outside of the outer border of the pan. Approximately 6 fluid ounces of water and 12 fluid ounces of fuel were poured into the pan; the mixture was then ignited by a hand-held propane torch. Heat flux was recorded in one second increments starting when the fuel was ignited. Mass of the pan was manually recorded in 10 second increments to record mass loss of the fuel. Table 3 shows the order in which testing took place. Figure 1 displays the laboratory set-up.

The flash point test was conducted per ASTM D93-07 “Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester”.

**Table 3: Test matrix for the lab-scale fire evaluations**

| Test Number | Fuel Tested |
|---|---|
| 1 | JP-8 |
| 2 | 50/50 Blend (JP-8/S-8) |
| 3 | Synthetic JP-8 (S-8) |
| 4 | Synthetic Diesel (S-2) |
| 5 | Diesel |
| 6 | 50/50 Blend (JP-8/ Shell FT-IPK) |
| 7 | Synthetic JP-8 (FT-IPK) |

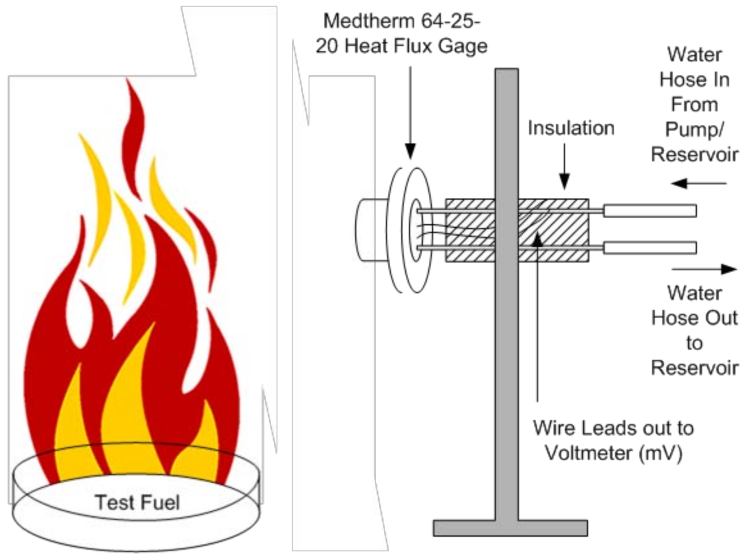


**Figure 1: Lab-scale evaluations set up**

### 3.3 Results

Table 4 shows densities and flash points of each fuel measured in the laboratory along with the MSDS values. Both the densities and flash points were comparable to the MSDS values. These values provided confidence that the fuels received were the fuels planned for the test evaluations.

**Table 4: Measured density and flash point**

| Fuel | Measured Density | MSDS Reported Density | Measured Flash Point | MSDS Reported Flash Point |
|---|---|---|---|---|
| Synthetic Diesel (S-2) | 0.76 g/cm$^3$ | 0.77 g/cm$^3$ | 59 - 60 °C | > 60.5°C |
| Synthetic JP-8 (S-8) | 0.75 g/cm$^3$ | 0.76 g/cm$^3$ | 52°C | 37.8 - 51.5 °C |
| Synthetic JP-8 (FT-IPK) | 0.73 g/cm$^3$ | 0.80-0.82 g/cm$^3$ | 39 - 40 °C | 38°C |

Figures 2 - 4 represent the incident heat flux recorded for both jet fuels and diesel fuels burning in a typical diffusion flame pattern characteristic of standard small-scale pool fires. The initial heat flux spike on each chart was used to record the time 0 on all charts. The intent of this controlled laboratory testing was to ensure that the heat release of all experimental fuel combinations is on the same order of magnitude as standard fuels to ultimately reduce firefighting risk in the full-scale fire suppression test application. Fluctuations in the data can be attributed to the oscillating laminar flame structure at the base of the fire driving the high energy turbulent release at the top of the plume. This interaction coupled with the cyclic ingestion of cool ambient air drive this inherently unsteady flow pattern. This analysis showed that the synthetic fuels did not have substantially higher heat flux values than JP-8; it was determined that existing fire test and safety equipment would be appropriate for larger scale fire suppression evaluations.

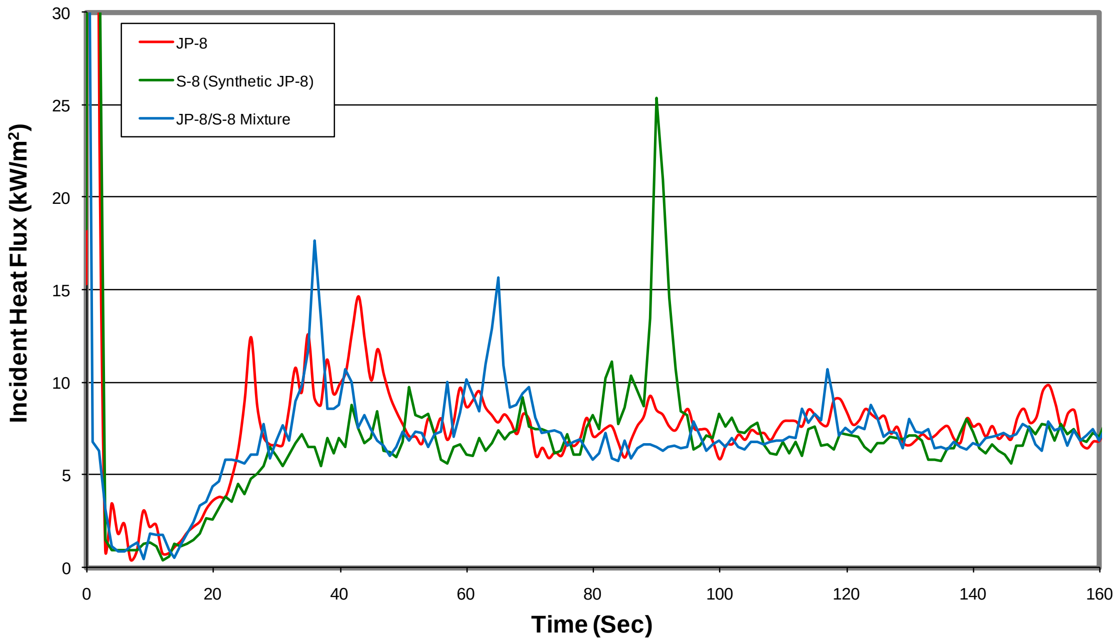


**Figure 2: Incident heat flux of JP-8 and S-8 jet fuel fires**

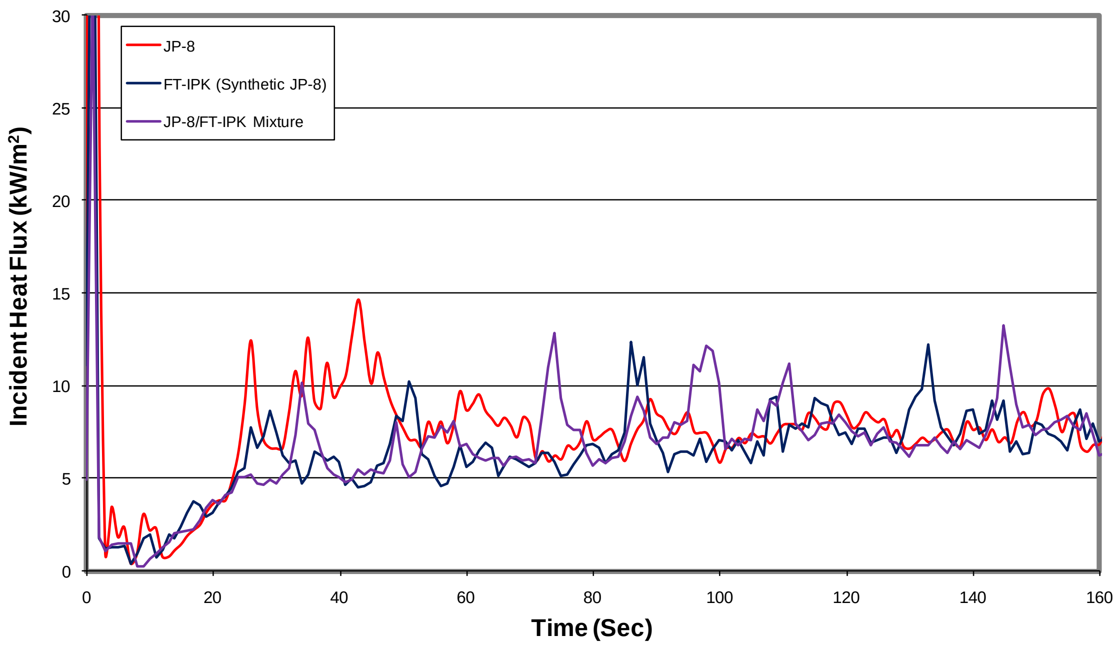


**Figure 3: Incident heat flux of JP-8 and FT-IPK jet fuel fires**

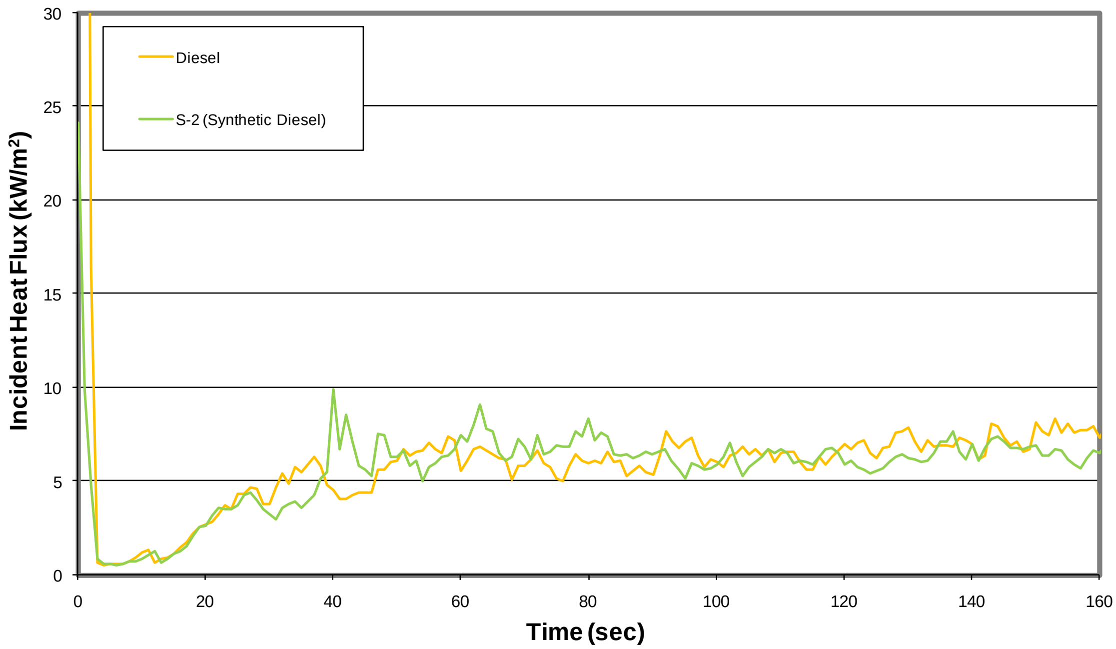


**Figure 4: Incident heat flux of diesel fuel fires**

Mass loss of the fuels was recorded during combustion starting when the fuel was ignited. The 6.5-inch diameter porcelain pan was positioned on a mass balance. Normalized mass results (by initial mass) are shown in Figure 5. In order to determine a mass loss rate for each fuel, the mass data during the initial part of each fire was discarded. During this time period mass loss rates fluctuate as the liquid fuel temperature varies. Mass loss for each fuel was determined based upon results during the last 60 seconds of the fire (Table 5). These results show a minor but observable difference in the fuel mass release rate with the diesel fuels (conventional and S-2) having 0.18 g/s on average and other jet fuels (including blends) having 0.20 g/s on average.

**Table 5: Measured mass loss rate during laboratory fires**

| Fuel Tested | Mass loss rate during 100 -160 seconds (g/s) |
|---|---|
| JP-8 | 0.20 |
| Synthetic JP-8 (S-8) | 0.19 |
| 50/50 Blend (JP-8/S-8) | 0.21 |
| Synthetic JP-8 (FT-IPK) | 0.20 |
| 50/50 Blend (JP-8/ Shell FT-IPK) | 0.20 |
| Diesel | 0.19 |
| Synthetic Diesel (S-2) | 0.18 |

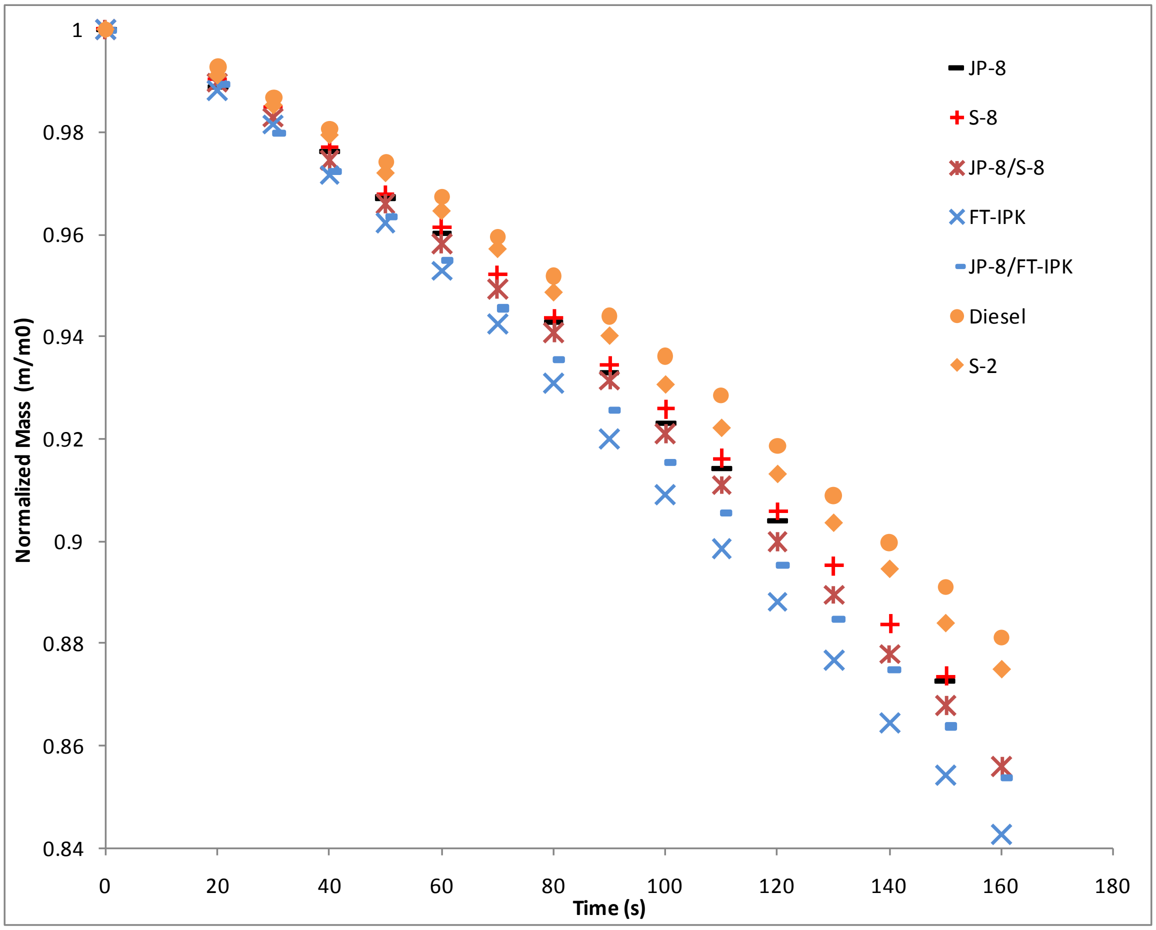


**Figure 5: Mass Loss of JP-8, diesel and synthetic fuel fires**

## 4.0 Medium-Scale Evaluations

### 4.1 Description

All medium-scale evaluations were conducted in the Fire Hanger at AFRL Test Range II, Tyndall AFB, FL. The Fire Hanger building is 75-feet x 75-feet with a maximum height of 31-feet (Figure 6). This facility provides an indoor fire test environment conducive to repeatable results and eliminates the impact of adverse weather conditions on the fire. All evaluations were performed with the hanger doors closed to eliminate the effect of air currents on the fires.

**Figure 6: Fire Hanger at Tyndall Air Force Base**

#### 4.1.1 Test Pans

The test pans were assembled using ¼-inch thick stainless steel. Figure 7 illustrates the six-foot diameter (28 $ft^2$) pan with a four-inch high side and the one-foot diameter burnback pan with a two-inch high side. The pans were fabricated as specified in MIL-F-24385F.

**Figure 7: The 28 $ft^2$ test pan and the one-foot burnback pan**

#### 4.1.2 Extinguisher and Nozzle

To ensure a consistent 100 psi nozzle pressure with a 2 gallons per minute (gpm) flow rate, a ten gallon volume flightline extinguisher was used as a pressure vessel attached to a regulated nitrogen gas cylinder. Shown in Figure 8 are the flightline extinguisher and the 2 gpm nozzle utilized in the tests. The pressure at the nozzle was verified before each test and the agent flow rate verification was performed after every two tests to ensure consistency in testing. A 50-foot, one-inch diameter hose was connected between the extinguisher and the nozzle.

**Figure 8: Ten-gallon flightline extinguisher and the 2 gpm nozzle**

### 4.1.3 Firefighting Agent

Chemguard 3% qualified products list (QPL-24385-26) MIL-SPEC AFFF (Figure 9) was used as the firefighting agent in all tests. To eliminate the fire suppression agent as a variable in these evaluations, the agent and the concentration that the agent was mixed with water (3%) did not vary throughout the testing.


**Figure 9: Commercially available 3%AFFF**

### 4.1.4 Fuels Tested

Table 6 reveals the test matrix for the fuels evaluated. The S-8 and S-2 fuels were delivered from the manufacturer without Air Force corrosion inhibitor and anti-icing additives. These additives were included in the remaining fuels that were evaluated; their exclusion from the two fuels was not believed to have a negative impact on these tests or to adversely affect the burning characteristics of the fuels.

**Table 6: Fuels test matrix**

| Type of Fuel | Number of Tests |
|---|---|
| S-8 | 4 |
| JP-8 | 4 |
| Shell (FT-IPK) | 5 |
| JP-8 / S-8 Blend | 5 |
| JP-8 / FT-IPK Blend | 6 |
| S-2 | 2 |

## 4.2 Procedures

Medium-scale evaluations followed the procedures in MIL-F-24385F, Section 4.7.13 for a 28 $ft^2$ fire test with the exception of preburn times. Preburn times varied as explained below.

Evaluations began by filling the 10-gallon fire extinguisher with 9.7 gallons of water and 0.3 gallons of Chemguard AFFF. The extinguisher was then pressurized to 100 psi with nitrogen. To insure a successful test, the nozzle was verified to disburse 2 gpm of solution.

A shallow layer of freshwater, approximately 0.25-inches deep, was dispensed in the bottom of the six-foot diameter pan to guarantee complete coverage of the area with fuel and to protect the pan's bottom. Ten gallons of fuel was poured into the 28 $ft^2$ pan (Figure 10) to provide an approximate 0.5-inch fuel layer. The quantity of fuel specified ensures that results will not be affected by all of the fuel being consumed during the test. Within 30 seconds of pouring, the fuel was ignited.

**Figure 10: Firefighter pouring the fuel into the 28 $ft^2$ pan**

The preburn for this type of test with unleaded gasoline is typically 10 seconds before the firefighter is permitted to attack the fire. Preburn is measured from fuel ignition until agent is applied to the fire. With unleaded gasoline, 10 seconds is sufficient for the fuel in the test pan to be considered fully involved in flames. Due to the less volatile nature of each of the fuels evaluated in this test series, a different method was devised to ensure a fully involved fire each test.

After ignition, the fuel was allowed to burn freely until the flames spread across the pan and exhibited pulsing behavior. The test director then allowed the fire to burn for an additional five seconds before instructing the firefighter to attack the fire. With this preburn method, the total time from ignition to full involvement may vary significantly from test to test with the same fuel or different fuels for reasons such as initial fuel temperature, flash points, or how long the ignition source is applied to the fuel. These variations are not significant. By ensuring a consistent, fully involved fire before beginning agent application, reliable extinguishment and burnback results were ensured.

After the preburn, the fire was "attacked and extinguished as expeditiously as possible" (IAW MIL-F-24385F), with agent first applied to the center and then the outer edges to effectively coat

and extinguish the flames (Figure 11). The moment of extinguishment was recorded and foam application continued for a total of 90 seconds (Figure 12), which ensures a consistent agent volume of three gallons used in each test.

**Figure 11: Firefighter aggressively fighting the fire**

**Figure 12: Continuing to apply foam after extinguishing the fire**

Within 60 seconds of completing the foam application, the one-foot diameter pan containing flaming unleaded fuel was placed in the center of the six-foot diameter pan to begin the burnback portion of the evaluation (Figure 13). This portion of the test provides information on the relative safety of a fuel spill that is covered by a foam blanket. When the fire had spread outside the small pan and was burning steadily, the small pan was removed. The burnback time was recorded when 7 $ft^2$ (25%) of the total area was covered in flames.

**Figure 13: Placing the burnback pan**

### 4.3 Results

Unleaded gasoline is typically used in this six-foot diameter test pan to evaluate AFFF performance. MIL-F-24385F has the following specifications (Table 7) for an AFFF fire suppression test in the 28 $ft^2$ pan:

**Table 7: MIL-F-24385F specifications for unleaded gasoline in a 28 $ft^2$ pan**

| Fuel | Preburn Time (sec) | Extinguishing Time (sec) | 25% Burnback Time (min) |
|---|---|---|---|
| Unleaded Gasoline Standard | 10 | 30 | 6:00 |

Figure 14 shows a typical preburn for an unleaded fuel fire. The 28 $ft^2$ pan is fully involved after three seconds and fire suppression begins after ten seconds. Figures 15 and 16 show the slower propagation of higher flash point fuels. In each test the fires were allowed to become fully involved before fire suppression was initiated.

**Ignition** **Ignition + 0.5 seconds** **Ignition + 3 seconds**

**Figure 14: Unleaded gasoline flame propagation**

**Ignition** **Ignition + 10 seconds** **Ignition + 15 seconds**

**Figure 15: JP-8 flame propagation**

**Ignition** **Ignition + 12 seconds** **Ignition + 24 seconds**

**Figure 16: SPK flame propagation**

The extinguishment time and burnback time for JP-8 was compared to each fuel or fuel mixture. This was done by performing t-tests on the recorded data, comparing JP-8 with corresponding fuels or mixtures. The hypotheses tested were that the time to extinguish ($t_{ex}$) the synthetic fuels and the burnback time ($t_{bb}$) of the synthetic fuels were no different than the times for JP-8. If the probability resulting from the t-test was less than 5%, the comparison was statistically significant. If the probability values were greater than 5%, no statistical difference in the times could be determined from the sample sets. The t-test assumes that the samples have equal variance and follow a normal distribution. A t-statistic ($t$) is calculated by

$$t = \frac{\overline{X}_{JP-8} - \overline{X}_i}{\sigma_{X_{JP-8}X_i}\sqrt{1/n_{JP-8} + 1/n_i}} \tag{1a}$$

$$\sigma_{X_{JP-8}X_i} = \sqrt{\frac{(n_{JP-8}-1)\sigma^2_{JP-8} + (n_i - 1)\sigma_i^2}{DF}} \tag{1b}$$

$$DF = n_{JP-8} + n_i - 2 \tag{1c}$$

where the subscripts *JP-8* and *i* represent the data sets for JP-8 and the comparison fuel (named *i* in Eq. 1), respectively. $\overline{X}$ is the average, $\sigma$ is the standard deviation, and $n$ is number of data points collected for the particular data set. $\sigma_{X_{JP-8}X_i}$ is a common standard deviation between the two fuel samples, and *DF* are the degrees of freedom for the two data sets. The probability is determined by a two-tailed normal distribution which is a function of *t* and *DF*.

$$p = f(t, DF) \tag{2}$$

If the probability resulting from that t-test was greater than 5%, the hypothesis was rejected indicating that no difference in the extinguishment or burnback times could be determined from the sample sets. The average values as well as confidence intervals (95%) were also determined. Figures showing these values will be discussed below in Section 4.3.5.

### 4.3.1 Conventional JP-8 Fuel

JP-8 was evaluated to establish a baseline for comparison with synthetic fuels and conventional/synthetic blended fuels. JP-8 required a mean preburn time of 23.5 seconds to become fully involved. AFFF extinguished the JP-8 fires in an average time of 23.8 seconds and had a burnback average time of 11 minutes and 19 seconds. Table 8 shows the results from the

JP-8 fires. Although not measured, the smoke emerging from the JP-8 fires qualitatively appeared denser than for the other fuels.

**Table 8: JP-8 fuel results**

| Test Number | Preburn Time (sec) | Extinguishment Time (sec) | 25% Burnback Time (min) |
|---|---|---|---|
| 1 | 24 | 26 | 10:38 |
| 2 | 16 | 21 | 12:18 |
| 3 | 21 | 20 | 10:01 |
| 4 | 33 | 28 | 12:21 |

### 4.3.2 SPK Jet Fuels

The S-8 and FT-IPK alternative fuels required a preburn time mean of 21.8 seconds. The S-8 and FT-IPK average extinguishment time were 25.3 and 25.6 seconds respectively. The burnback averages were 13:17 and 13:57 respectively. Table 9 displays the results of the two SPK fuels tested. Athough not measured, there was a noticeable decrease in the amount of smoke produced as compared to JP-8 fires.

**Table 9: SPK fuel results**

| SPK Jet Fuel Tested | Preburn Time (sec) | Extinguishment Time (sec) | 25% Burnback Time (min) |
|---|---|---|---|
| S-8 | 20 | 27 | 13:53 |
| S-8 | 20 | 26 | 14:15 |
| S-8 | 26 | 21 | 12:25 |
| S-8 | 33 | 27 | 12:35 |
| FT-IPK | 23 | 22 | 14:02 |
| FT-IPK | 20 | 27 | 13:31 |
| FT-IPK | 20 | 20 | 14:18 |
| FT-IPK | 20 | 30 | NBB* |
| FT-IPK | 15 | 29 | NBB |

*NBB – No Burnback

The probability for extinguishment time between JP-8 and the SPK fuels was calculated as described in 4.3. Results were probabilities of 55.6% for the S-8 fuel and 53.0% for the FT-IPK fuel. Since the probability was greater than 5%, hypothesis that these fuels were different was rejected. It can be assumed that AFFF can extinguish both of these SPK fuels equal to that of JP-8. Similarly for the burnback time, the probability for burnback time of the S-8 fuel was 4.0% and the FT-IPK fuel was 1.5%. This shows that the burnback time was significantly different for both fuels with the SPK fuels having the higher average. With the longer burnback time for the SPK fuels as compared to JP-8, these results indicate that there is increased safety when using the synthetic fuels.

### 4.3.3 SPK/JP-8 Blended Jet Fuels

The 50/50 mixture of SPK and conventional JP-8 outcome varied. The FT-IPK/JP-8 blend required an average 24.3 second preburn in order to have a fully engulfed fire, and the S-8/JP-8 blend averaged 22.2 seconds. The S-8 blend extinguishment mean was 23 seconds and the FT-

IPK blend mean was 25.5 seconds. The burnback times reflected more significant differences. The FT-IPK blend had an average burnback time of 11 minutes and 18 seconds. The S-8 blend had a 13 minutes and 55 seconds average burnback time. The results from the tested blends are listed in Table 10.

**Table 10: SPK/JP-8 blended fuel results**

| 50/50 Blend Tested | Preburn Time (sec) | Extinguishment Time (sec) | 25% Burnback Time (min) |
|---|---|---|---|
| S-8/JP-8 | 18 | 18 | 13:36 |
| S-8/JP-8 | 24 | 24 | 13:50 |
| S-8/JP-8 | 25 | 24 | 14:00 |
| S-8/JP-8 | 27 | 24 | 14:30 |
| S-8/JP-8 | 17 | 25 | 13:40 |
| FT-IPK/JP-8 | 23 | 29 | 11:21 |
| FT-IPK/JP-8 | 28 | 26 | 10:52 |
| FT-IPK/JP-8 | 20 | 24 | 13:18 |
| FT-IPK/JP-8 | 26 | 23 | 10:58 |
| FT-IPK/JP-8 | 26 | 24 | 11:01 |
| FT-IPK/JP-8 | 23 | 27 | 10:23 |

The calculated probability for extinguishment time between JP-8 and a blend of S-8 and JP-8 was 74.6%. For the FT-IPK/JP-8 blend the probability was 38.7%. The probability for burnback time of the S-8 blend was 0.2% and the FT-IPK blend was 98.8%. The S-8 blend performed similar in burnback to the SPK fuels by themselves. However, the FT-IPK blend performed similar to JP-8 for burnback. This may be due to the flash point for the FT-IPK fuel being lower than the flash point of S-8 (see Tables 1, 2, and 4).

### 4.3.4 Synthetic Diesel Fuel

Two tests were conducted with the synthetic diesel (S-2). S-2 had an average extinguishment time of 27.5 seconds. The burnback mean was 14 minutes and 3 seconds. The results are shown in Table 11. Like the results of the synthetic jet fuels, AFFF was effective on this fuel as compared to JP-8. The probability for extinguishment was 26.7% while the burnback time was 4.4%. Again because of its higher flash point, the burnback time showed improved performance for the S-2 fuel than JP-8.

**Table 11: Synthetic diesel fuel results**

| Test Number | Preburn Time (sec) | Extinguishment Time (sec) | 25% Burnback Time (min) |
|---|---|---|---|
| 1 | 27 | 28 | 13:33 |
| 2 | 26 | 27 | 14:33 |

### 4.3.5 Discussion

Table 12 displays the average results of each fuel evaluated. The average for extinguishment and burnback time as well as their confidence intervals (95%) are plotted in Figures 17 and 18. The results show that AFFF is a very effective firefighting agent against synthetic fuel fires and that the performance of AFFF on synthetic fuel is similar to that of JP-8 fuel. The higher flash

points, slow surface flame propagation (as evidenced by longer required preburns), as well as the longer burnback times of the SPK jet fuels and SPK blends indicate the safer nature of these fuels. The synthetic fuels with lower volatility showed improved fire suppression behavior than the JP-8 fuels.

**Table 12: Average results**

| Fuel | Average Pre-Burn Time (sec) | Average Extinguishing Time (sec) | Average 25% Burnback Time (min) |
|---|---|---|---|
| JP-8 | 23.5 | 23.8 | 11:19 |
| S-8 | 24.8 | 25.3 | 13:17 |
| FT-IPK | 19.6 | 25.6 | 13:57 |
| S-8/JP-8 Blend | 22.2 | 23 | 13:55 |
| FT-IPK/JP-8 Blend | 24.3 | 25.5 | 11:18 |
| S-2 | 26.5 | 27.5 | 14:03 |

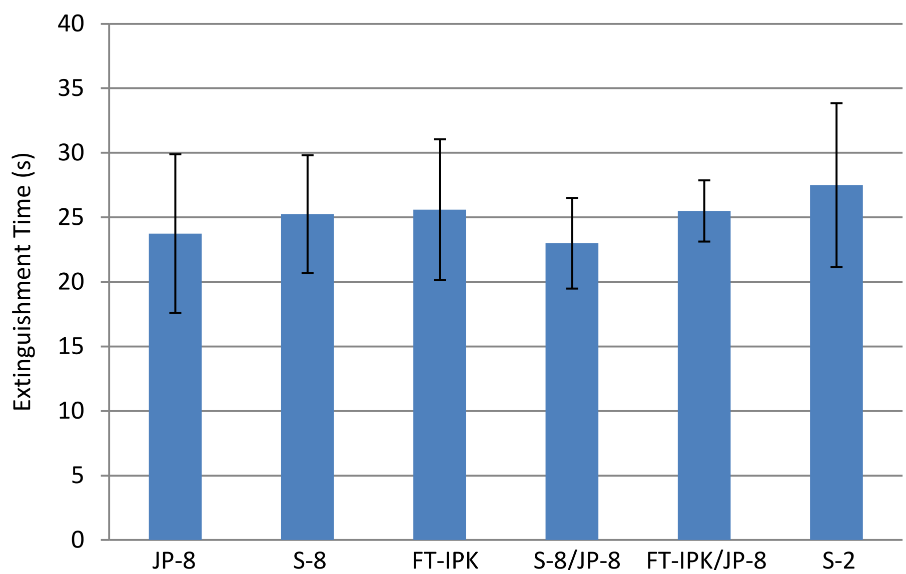


**Figure 17: Average extinguishment times (with 95% confidence intervals) for various fuels**

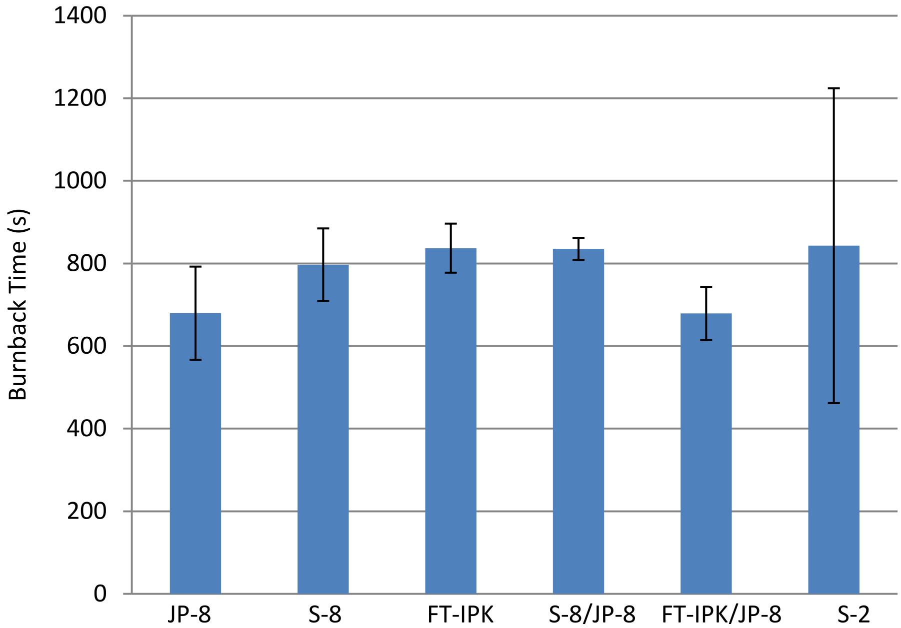


**Figure 18: Average burnback times (with 95% confidence intervals) for various fuels**

## 5.0 Conclusions and Recommendations

### 5.1 Conclusions

Test results show AFFF with current firefighting equipment will extinguish the tested synthetic fuel fires just as effectively as conventional fuel fires. The prolonged burnback times indicate that AFFF is equal to or more effective at preventing burnback of the tested synthetic fuels and fuel blends than with JP-8 fuel.

### 5.2 Recommendations

As novel combustible energy sources emerge as viable replacement candidates for traditional petroleum-based fuels, it is recommended that each new fuel undergo a minimum series of evaluations using the methods discussed in this report to ensure the safety of firefighters and effectiveness of firefighting equipment and agents. A larger number of experiments should be conducted if increased data confidence levels are required.

## 6.0 References


1. Military Specification, MIL-F-24385F. “Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, For Fresh and Sea Water”, 7 January 1992.

2. Military Specification, MIL-DTL-83133F, “Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)”, 11 April 2008

3. Moses, Clifford A. (2008) “Comparative Evaluation of Semi-synthetic Jet Fuels”, Report for Coordinating Research Council, Inc. and Universal Technology Corporation. CRC Project No. AV-2-04a. September 2008.

4. Woodward, Steven R. (2001) “Letter to Ms. Linda Bluestein of the Alternative Fuel Transportation Program of the US-DOE concerning EPAct Petition of Syntroleum Fuels”, Dated September 12, 2001, Received September 18, 2001.

5. ASTM D93-07, American Society for Testing and Materials. “Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester”.

6. MIL-HDBK-510(USAF), “Aerospace Fuels Certification”.

## 7.0 List of Symbols, Acronyms, and Abbreviations

| Abbreviations | Description |
|---|---|
| °C | Degrees Celsius |
| °F | Degrees Fahrenheit |
| 50/50 | Half & Half |
| AFFF | Aqueous Film Forming Foam |
| AFRL | Air Force Research Laboratory |
| DF | Degrees of freedom |
| $ft^2$ | Square Feet |
| FT | Fischer-Tropsch |
| gpm | Gallons Per Minute |
| $in^2$ | Square Inches |
| JP-8 | Jet Propellant i.e. Jet Fuel |
| kW | Kilowatts |
| lpm | Liters Per Minute |
| $m^2$ | Square Meters |
| mL | Milliliters |
| Mil-Spec | Military Specification |
| Min | Minute |
| MSDS | Material Safety Data Sheet |
| mV | Millivolts |
| NBB | No Burnback Tested |
| p | Probability |
| Psi | Pounds Per Square Inch |
| QPL | Qualified Products List |
| RXQD | Fire Research Team |
| SPK | Synthetic Paraffinic Kerosene |
| S-2 | Syntroleum Synthetic Diesel |
| S-8 | Syntroleum SPK Jet Fuel |
| Sec or s | Seconds |
| $t_{bb}$ | Burnback time |
| $t_{ex}$ | Extinguishment time |
| FT-IPK | Shell Oil SPK Fischer-Tropsch Iso-Paraffinic Kerosene |
| USAF | United States Air Force |